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Climate and Clothing

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Problems in the Army

Climate may be described as refined weather. The meteorologist has noted the day-to-day variations of the weather components, has extracted the principal frequencies which then describe the seasons, and, once the average values have been derived over long periods of time, there emerges the concept of climate (Adam 1967). The earliest traceable civilizations seem to have arisen in a succession of areas close to the 70°F (21°C) isotherm as it is known today. Markham (1944) agrees that changes in climate have occurred since the dawn of civilization, but not sufficiently to invalidate his argument. The discovery of coal and the invention of the fireplace, by which man was able to create a 'private environment', did more to open new (and colder) regions for population than any other factor (Burton & Edholm 1955). Homeothermic man has since increased enormously the range of environments in which he can live by the acquired and transmitted skills involved in clothing, shelter, heating of dwellings and, finally, their air-conditioning.

The heat exchanges of man with his environment have been the subject of intensive study since the days of Rubner. Workers famous in this century for outstanding and fundamental advances in knowledge in this field are Bedford in the United Kingdom, Lee in Australia, and a long list from the United States which includes Dubois, Yaglou, Houghton, Winslow, Gagge, Herrington, Dill and his group. Burton (1946), however, has made the plea that this earlier work was intensive rather than extensive in scope, and not, therefore, entirely suitable for those who have to face environmental extremes in which physiological adjustments suffice for only a limited range of external fluctuations.

Elements of Climate

The higher organisms have been emancipated from changes in the environment by the constancy of the 'milieu intérieur', described by Claude Bernard in 1878. Man has achieved this by providing himself with clothing and shelter, the 'milieu intermédiaire' which softens the environmental blows until they lie within his survival range.

The components of climate that are of importance, both in and out of doors, in considerations of clothing are solar radiation, air temperature, humidity and air movement. Precipitation and cloud cover are additional factors which merit attention outdoors. Meteorologists, unfortunately, do not use all these components when classifying climates, and so the physiologists and the Services have evolved their own classification – hot/dry, hot/wet, temperate, cold/wet, cold/dry and high altitude. Such classification is simple, albeit without much meteorological basis, and adequately descriptive for most purposes, provided that it is recognized that overlaps can occur. A particularly dangerous example of the latter exists in the Persian Gulf area, in which the hot/dry climate of the desert has, at certain seasons, the elevated humidity which is more generally associated with the hot/wet climate of the jungle, but here modified by the higher air temperatures.

Scope of Clothing

The outbreak of modern warfare from 1939 onwards has brought a continuous challenge to the physiologists in the endeavour to render and keep men fit to fight, whatever the circumstances. Advances in preventive and curative medicine are

such that man is left virtually with only his two oldest enemies to combat – his fellow men and the environment, and he will be able to give better attention to the former if the latter is neutralized by the supply of clothing designed to keep him comfortable.

The theoretical function of the service-man's clothing is two-fold; first, to aid in maintaining the body's heat balance without endangering the thermoregulatory processes, and secondly, to protect the skin from mechanical and biological injury. In practice, however, the protection of the fighting man in the tropics forces a compromise between his effective role and his thermal balance. In the desert, with its high diurnal temperatures and nocturnal cold, evaporative cooling in the daytime is reduced by load-carriage and the requirement to protect the man's skin from the terrain, thorns, radiant energy and dust. Similarly in the humid jungle, where evaporative and convective cooling are jeopardized by load carriage and clothing protection against plants, insects, leeches and the like.

Cold weather clothing calls for windproof outer garments to prevent heat loss by convection, of durable material to minimize further heat escaping through tears and rents, and permeable to water vapour so that insensible perspiration may escape without condensing in the clothing. The undergarments are fitted on the layer principle (Adam & Goldsmith 1965) to provide sufficient insulation without interfering with agility or fine movements. The cold/wet climate has required the addition of the quality of water resistance or water repellency, to those mentioned above, for outer garments. The reason lies in the fact that no material has as yet been proved to be both water vapour permeable and waterproof simultaneously.

'Clo unit' of Thermal Insulation

The introduction of the 'clo unit' was due to the collaboration of three groups of workers, and Burton (1946) has given this description of it:

'"One Clo unit of thermal insulation in clothing suffices to keep a sitting-resting subject (Metabolic rate 50 Cals/Sq.M./Hr.) at 70°F. (21°C.), Relative Humidity less than 50%, air movement 20 ft./min. (10 cms./sec. or "still air") indefinitely in a comfortable steady state."

'We found that we could explain even to a General or Admiral, without a course in physics for which he had neither time nor patience, that his uniform had about One Clo unit of thermal insulation, his greatcoat another one Clo unit, and that together they provided him with a total of Two Clo units.'

Investigations into the use of the clo unit soon involved considerations of metabolic rates and then of tolerance times in varying cold environments. There emerged the fact that the maximum a man could wear was 4–5 clo units if he were to remain mobile and dexterous enough for military tasks; hence the importance of tolerance times as a compromise between effective role and the prevention of non-battle casualties due to the climate, already referred to in relation to tropical service.

The cold/wet environment, however, presents the greatest problem of all, and has caused perhaps more climatic casualties than the rest put together. The problem is that of keeping the clothing free of moisture from both external and internal sources. The most recent information on casualties and fatalities has been accumulated by Pugh (1966*a*) from a population ranging from schoolboys to Royal Marine Commandos. His experimental work (Pugh 1966*b*, 1967) showed that the dry clothing worn by one of the fatalities had an insulation value of 1·5 clo units, falling to 0·17 clo (15%) under conditions of exercise, wind and wetting, as well as providing an explanation of the premature fatigue commonly found in accidental hypothermia.

Warning Indices of Climatic Stress

The preservation of thermal balance in the tropics can only be achieved at the expense of the effective role of the soldier, by decreasing his metabolic heat production. The simplest method of achieving this end is by use of the apparatus for measuring the Wet Bulb Globe Temperature (WBGT) Heat Stress Index. First introduced into the British Army as a simplification of the Effective Temperature Scale by the Desert Test Team under Yaglou in 1956, its successful use has been reviewed by Minard & O'Brien (1964). The Royal Naval Personnel Research Committee has designed a WBGT Index meter which at present is undergoing validation trials. This instrument is preferred, personally, to the Army version since it has been modified to supply a measure of air-speed, thus allowing it to be used in cold environments for the second warning index – the Windchill index.

Increasing wind with a low or falling air temperature in a cold climate will sooner or later affect the mobile soldier's thermal balance to the extent that he must seek shelter, if he is not to become a casualty. The simplest index of value in these circumstances is that of Windchill, formulated by Siple & Passel (1945), in which only air speed and air temperature are required. It is suggested that it would be of practical value to military and civilian parties exercising in cold/wet conditions if this index were used by decreasing the air temperature by an arbitrary amount, say 6°C (11°F), to indicate the extra cooling due to wetting of the garments in conditions of wind and cold.

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Air-Insulated Clothing for Specific Naval Purposes

The protection of personnel against the adverse effects of exposure to extremely hot or cold environments is not a specifically naval problem, but the many and varied duties carried out by men of the Royal Navy render exposure to such hostile climates a distinct possibility. Accordingly, ways and means have been sought whereby men can continue to work effectively in such environments without danger to their health and well-being. Another aspect of the problem is to provide equipment which will enable men to survive in a lethally hot or cold environment long enough to effect an escape or await rescue.

Individual protection against thermally hostile environments may be provided by investing the body in some form of garment which will maintain a physiologically acceptable micro-climate within it. Such garments may be made from a thermally insulating material which will either serve to prevent the dissipation of metabolic heat to the environment and thus keep the body warm, or prevent heat from reaching the body from outside according to the direction of the thermal gradient. Additional heating or cooling of the micro-climate within the suit may be incorporated if a source of power is available.

It is the purpose of this paper to describe four suits which have been or are being developed to meet specific naval requirements, all of which utilize the thermal insulation properties of air.

Protection Against the Cold/Dry Environment

Assuming that electrical power is not available, the problem of keeping men warm in a cold/dry climate resolves itself into a need to provide clothing which will prevent metabolic heat from leaking into the environment, and the use of fabrics which contain much air trapped within their structure is a useful way of achieving this object. Obviously, however, wind effects would seriously disturb the insulating properties of such materials and, therefore, the outermost layer of the clothing should be windproof and waterproof.

At one time it was thought necessary to use heavy fabrics to protect the body against cold but nowadays new materials have been evolved which enable garments to be made from light, windproof materials which offer good protection against cold and yet allow the wearer to be fully mobile. For naval purposes the materials used in the manufacture of protective clothing must be chosen with great care to ensure that the fabric will offer sufficient insulation, stand up to rough usage, be easily stowed within the limited confines of a ship and be easily laundered. In view of the varied climatic conditions which may be met it is also better to have an assembly composed of several layers which may be shed or added to as circumstances demand.

In 1966 a trial was carried out in the stratosphere chamber of the British Aircraft Corporation, Weybridge, conjointly by the Director of Victualling, the Air Medical School and the Royal Naval Medical School, to test various items of foul-weather clothing in a climate of −20°C (−4°F) with wind speeds of up to 30 knots. Four volunteers wearing various clothing assemblies were exposed once daily on four successive days to the environment for periods of up to 2 hours during which time their skin temperatures at the left index finger, left cheek, back of neck, left thigh and left great toe were recorded using thermistor temperature sensors and their deep body temperatures by means of 'radio pills' (Wolff 1961). It had been decided to withdraw a subject from the climate if his deep body temperature fell below 35°C (95°F), if the skin temperature at any site fell below 8°C (46°F) or if there was a complaint of painful cold in any part of the body. Four of the sixteen exposures lasted the full 2 hours and of the remaining twelve, eight were terminated because of subjective complaints (seven of cold hands and/or feet and one of a cold nose) and four on medical advice because of undesirably cold extremities. There were no withdrawals due to an excessive fall in deep body temperature.

A full report on these trials will be available in the near future, but it is of interest in the present context to note that the standard reference clothing assembly for the head, trunk, arms and legs, composed entirely of items already available in the Royal Navy, gave adequate protection to those parts in the climate used in the experiment. This is not to say that electrically heated suits are of no advantage, indeed they probably are, but it